STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

A REPORT ON THE CORROSION OF THE UNDERGROUND SPRINKLER SYSTEM AT THE PACIFIC STATE HOSPITAL

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT

February 6, 1959

Lab. Proj. Auth. 72-S-6156

Mr. Anson Boyd
State Architect
Sacramento, California

Attention: Mr. Carlton L. Camp, Supervising Architect

Dear Sir:

Submitted for your consideration is:

A REPORT ON

THE CORROSION OF THE UNDERGROUND SPRINKLER

SYSTEM AT THE PACIFIC STATE HOSPITAL

Study made by . . . . Structural Materials Section
Under general direction of . . . . J. L. Beaton
Work supervised and report prepared by . . . . R. F. Stratfull

Very truly yours,

F. N. Hveem
Materials and Research Engineer

RFS:mw
cc: J. W. Trask
Dept. of Mental Hygiene (8)
R. O'Dell

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I. INTRODUCTION

On August 8, 1958, Mr. Carlton L. Camp, Supervising Architect, requested by letter that the Materials and Research Department perform a corrosion survey at the Pacific State Hospital under Laboratory Project Authorization 72-S-6156. It was requested that a survey be performed to determine the problem areas and to also gather sufficient data to enable the Division of Architecture to prepare a cost estimate for repairs which is to be submitted for the Governor's Capital Outlay Budget of 1959-1960.

Historically, the hospital has incurred stage construction or expansion of facilities since approximately 1932. In 1954 and also in 1956 additional new facilities were constructed.

The underground lines which were installed during and after 1932 have had to date the normal and expected amount of corrosion for an installation with an anticipated service life of 20 years or more. However, the underground facilities which were installed in 1954 and 1956 have had corrosion leaks in the sprinkler system within one year after construction.

A more complete historical background of the problems incurred at the hospital due to the corrosion of the new sprinkler system will be found in a letter dated May 22, 1958, to Mr. M. E. Porter, M. D., Director, Mental Hygiene, Attention of Mr. C. E. Applegate, Deputy Director, from Mr. R. W. Hages, Assistant Superintendent, Pacific State Hospital, Spadra, California.

II. SUMMARY AND CONCLUSIONS

The predominant cause of the accelerated corrosion of the sprinkler system is its electrical interconnection to the reinforcing steel imbedded in the basement walls of the buildings.

Evidence of the cause of the corrosion includes the following: one, the rapid loss of the hose bibs which are adjacent to the buildings; two, the fact that approximately 70% of the leaks in the sprinkler system are within 50 feet of the reinforced concrete walls; three, the electrical potential measurements which indicate that corrosion currents from the buildings are causing the failure in the sprinkler piping.

The cost of the sprinkler systems which were installed under the contracts of 1954 and 1956 is estimated at $97,000.

The spot inspection of the sprinklers by the hospital maintenance personnel indicated that if the corrosion is not stopped, the entire sprinkler system will have to be replaced in the near future. The inspections of the maintenance personnel were accomplished by excavating and observing the unearthed pipe.

Due to the accelerated rate of corrosion, it is recommended that cathodic protection be applied to the sprinkler systems in the new areas of construction as soon as possible. Otherwise, deterioration of the sprinkler system will continue to be rapid, and accelerated corrosion of other underground piping may occur.

It is suggested that if the work is approved as an emergency item, the hospital maintenance personnel be utilized to install the cathodic protection system and that a representative of the Materials and Research Department and the Division of Architecture be present to supervise the techniques of cathodic protection and compliance with the electrical and construction codes.

It is estimated that the installation of the emergency cathodic protective system will effect an economic savings of $21,200.00 per year.

III. RECOMMENDATIONS

We recommend:

1. That an impressed current cathodic protection system be installed as soon as possible.

2. That the cathodic protection system be installed in two phases, the first phase to be the application of cathodic protection in the areas of the 1954 and 1956 construction. The second phase would be the application of cathodic protection to the remainder of the institution.

3. That the anode beds and electrical wiring system installed in the first phase be constructed in such a manner that they will be a permanent part of the final cathodic protection system.

4. That economical light duty rectifiers be purchased as a source of D. C. current. At the termination of their intended use, they should be placed in storage to be utilized as current sources for other emergency or light duty applications.

5. That the anode beds be placed as shown on Exhibit III.

6. That the hospital maintenance forces electrically isolate all underground lines where they enter each building. This does not include electrical, steam, or telephone lines.

7. That the second phase of the construction of the cathodic protection system consist of electrical isolation of the hospital piping from the public utility lines which service the hospital.

8. That if any buried private utility lines, such as telephone, gas or water, traverse the general area of the institution, officials of the companies concerned be notified of the State's intentions.

9. That underground lines such as telephone or electrical be checked for stray current corrosion. If necessary, a metering resistor should be bonded between any electrically isolated line and the water lines to apply sufficient cathodic protection current to prevent stray current damage.

10. That if any underground line is repaired or extended, the pipe be wrapped or coated.

11. That a trained person periodically check the operation of the cathodic protection system for a period of 6 weeks after installation.

12. That in the second phase of construction of the cathodic protection system permanent potential checking stations be established.

13. That the Materials and Research Department of the Division of Highways be informed of any additional leaks in the piping system after the installation of the cathodic protection system.

14. That at the conclusion of 6 weeks of operation of the cathodic protection system an equi-potential survey be made.

15. That at yearly intervals a corrosion survey be made of the piping system to substantiate the effectiveness of the cathodic protection system and to facilitate any necessary changes in the current output of the rectifiers.

16. That the hospital purchase such instruments to check the pipe to soil potentials.

17. That a representative of the Materials and Research Department, or other qualified person, instruct the hospital maintenance personnel in the mechanics of obtaining pipe to soil potentials.

IV. TESTS

A. Pipe to Soil Measurements

The flow of galvanic current from a corroding metallic structure can be detected by measuring the electrical voltage drop in the soil about the structure.

The voltage drop, or the pipe to soil potential, of the underground structure was measured with a standard copper sulfate half-cell and a vacuum tube voltmeter.

The results of the pipe to soil measurements made at Pacific State Hospital are shown on Exhibit I, Equi-Potential Contours.

As indicated by the pipe to soil measurements, there are many locations at which the water lines are now corroding. Also, anticipated future leaks are marked with the letter "F".

The stability and reproducibility of the pipe to soil potential measurements indicated that the corrosion problem is typically galvanic and is not caused by stray electrical currents.

As an additional check for stray currents, the pipe to soil potential was automatically recorded for 24 hours.

The continuous 24 hour recording showed that there was no voltage variation in 24 hours.

As shown by the pipe to soil potentials on Exhibit I, the electrical corrosion currents are caused by the presence of the buildings. Apparently the reinforcing steel in the reinforced concrete basement walls is electrically connected to the piping and is causing the corrosion. The connection of reinforcing steel to the piping occurs when piping that passes through the walls rests upon the reinforcing steel.

As will be noted, potential measurements were not performed over the entire hospital piping system. The reason that a complete survey was not performed was that it was considered more important to detect and verify the cause of corrosion rather than to verify the known fact of the presence of corrosion.

B. Electrical Resistivity of the Soil

Since the corrosion of the underground piping is electrochemical in nature, either the presence or the absence of certain chemicals is contributory to the magnitude of the galvanic currents developed. Likewise the electrical resistivity of the soil, through which the electrical corrosion currents must flow, has a direct bearing on the rate of

corrosion -- the lower the electrical resistivity of the soil, the greater the possible flow of current. In the final analysis a high current flow is directly related to a high rate of corrosion attack.

The electrical resistivity of the soil at the Pacific State Hospital is shown on Exhibit II, Equi-Resistivity Contour map. As shown by the earth resistivity measurements, the soil varies from 400 to 9000 ohm cm. The average in the 1954 and 1956 areas of construction is approximately 500 ohm cm and in the older (prior to 1954) areas of construction the resistivity of the soil is approximately 1500 ohm cm.

In the older parts of the hospital where the soil resistivity averages approximately 1500 ohm cm, the piping has lasted approximately 20 years before leaks were apparent.

With the deficiencies in construction and the approximately 500 ohm cm soil in the new areas of construction, the piping has been perforated by corrosion in approximately 1 year.

As will be noted on Exhibit II, Equi-Resistivity Contour map, the leaks are generally found in the areas where the electrical resistivity of the soil is at low value.

C. Miscellaneous Tests

1. Galvanic Current flow:

It was not economically feasible to disconnect the piping from any of the buildings in the new areas of construction. In the older areas of construction, the maintenance forces have installed electrical insulators between the sprinkler piping and the copper tubing for control of the automatic sprinklers and therefore provided electrical isolation of the copper and steel lines. Complete isolation was accomplished by disconnecting the lateral at the coupling to the main.

When an ammeter was inserted between the copper tubing and the steel sprinkler system, it was found that a current of approximately 0.25 amperes would flow and cause corrosion of the sprinkler system. For the uncoated mass of piping which is buried at the hospital grounds, a current flow of 0.25 amperes is not a matter of great concern; but if 0.25 amperes were concentrated on a 10' length of steel pipe, it would be entirely consumed within 3.5 years. However, in this case the corrosion currents of the copper tubing was not directed at a 10' length of pipe but the entire mass. It is therefore obvious that the concentration of small electrical currents could result in severe damage to underground piping, and the electrical inter-connection of dissimilar metals should be avoided.

2. Cathodic Protection Requirements

Cathodic protection current requirements were tested on the lines in the vicinity of cottage No. 11. According to the test data, it would require approximately 0.004 ampere of electrical current for every square foot of uncoated pipe to completely stop the corrosion.

Experimental test currents were also applied to the entire piping system in the vicinity of cottage No. 11, and the test indicated approximately 5 amperes of current would be required to protect the piping adjacent to each cottage.

Based upon the test currents, the anode beds, as shown in Exhibit II, Location of Anodes, were designed with a sufficient factor of safety to overcome the anticipated increased current for cathodic protection due to the electrical interconnection of the piping to the reinforcing steel in the buildings. However, if the maintenance forces have a continued program of electrically isolating the water lines from the buildings, the current required to cathodically protect the piping will be greatly reduced and will result in a more economical operation of the system.

V. LEAK FREQUENCY

The frequency of leaks in a utility system follows a definite mathematical function which is indicated by the plot of the accumulated leaks against time shown on Exhibit V in the Appendix.

Since the dates when the leaks in the sprinkler system were not recorded, only a generalized plot of the frequency of leaks can be estimated. As shown on Exhibit IV, Estimated Leak Frequency of Sprinkler System, the slope of the leak frequency curve is based upon a total of 18 leaks in four years.

Based upon the history of pipe replacement and the frequency of leaks at other state facilities, it appears that when 21 leaks appear in a piping system in a twelve month period, portions of that system are either abandoned or replaced. Therefore, it appears that the condition of the sprinkler system at Pacific State Hospital is in a borderline region between being saved by cathodic protection and requiring replacement. That the system is in a borderline condition is evidenced by the observations of the condition of the piping by the maintenance personnel and also by the leak frequency curve, which indicates that the critical point of approximately 21 leaks in twelve months will occur during 1959 or 1960.

Also included in the Appendix is Exhibit V, Plot of Hose Bib Leaks versus Time. As will be noted on this exhibit, the frequency of the loss of hose bibs was quite rapid. In fact, approximately 7 hose bibs were replaced as a result of corrosion within a 6 month period.

The loss of hose bibs would have continued at that rapid rate if the Chief of Maintenance at the hospital had not installed electrically insulating couplings when replacing a corroded hose bib.

VI. CAUSE OF CORROSION

The fundamental cause of the accelerated corrosion is the electrical connection of the piping system to the reinforcing steel primarily contained in the basement walls.

The other factors which influenced the accelerated rate of corrosion in the new areas of construction were:

1. The corrosive soil in which the pipes were installed.
2. The electrical interconnection of the sprinkler system to the main piping system.
3. The electrical connection, due to improper placement, of the copper control lines for the automatic sprinkler system.

VII. DISCUSSION

A. Electrical Interconnection of Underground Structures

Usually if a metallic pipe is buried in the earth, the possibility of the corrosion of the pipe will depend upon differences in environment in the system. For instance, when a network of different types of metallic pipes is placed in a corrosive soil and electrically interconnected, conditions that create the corrosion voltage are built into the system. The rate of corrosion will usually be controlled either by the anode to cathode area ratio (depolarization) or the electrical resistance of the ground.

In the older parts of the hospital, the sprinkler system was not electrically connected to the buildings. This resulted in approximately 20 years of service life before perforation of the lines began to occur.

This comparison of 20 years of service life for piping which was electrically disconnected and an estimated 3 years to perforation for electrically connected piping clearly presents the necessity for electrically isolating dissimilar metals or environments at the time of construction.

At the time of the investigation, the Chief of Maintenance at the hospital was in the process of electrically isolating the copper control lines from the sprinkler system in the older (prior to 1954) areas of construction.

It was suggested that he continue to isolate the copper lines from the steel piping to reduce the corrosion attack on the steel lines.

It was also brought out that in the new areas of construction (after 1954) that it would be economically unfeasible to electrically disconnect the copper control lines from the sprinkler system. The reason given was that during construction, the copper lines were laid in the trench at the same grade as the steel piping. As a result the sprinkler laterals and mains were mechanically and electrically interconnected when the meandering copper lines touched the steel lines. A suggested method for preventing a recurrence of the electrical interconnection of copper control and galvanized steel sprinkler lines would be to place one of the lines in the trench, backfill for a depth of 3" and then place the other line. This would prevent interconnection due to construction practices and then the electrical isolating couplings which were installed in the copper lines would be effective.

B. Soil Corrosivity

The most acceptable and significant criterion for anticipating or comparing the corrosivity of soils is the measurement of their electrical resistivity. The resistivity of soil is described in ohm-cm., which is the electrical resistance, in ohms, of a cube of soil one centimeter cubed.

The August 1931 issue of Western Gas presented the following classification of soil corrosivity as related to the specific electrical resistance of such soils:

Resistivity - ohm cm	Corrosivity
0 - 400	Severely corrosive
400 - 1200	Moderately corrosive
1200 - 4000	Mildly corrosive
4000 - 10000	Slightly corrosive

Resistivity - ohm cm	Probable Life of Bare Steel Pipe in Years
0 - 1000	0 - 9
1000 - 2500	9 - 15
2500 - 10000	15 or more

As will be noted, the soil at the Pacific State Hospital falls into two general classifications; mildly and moderately corrosive.

The mildly corrosive soil is generally in the prior to 1954 areas of construction and the table indicates a probable life of bare steel pipe of between 9 and 15 years. The moderately corrosive soil at the hospital is located in the areas which were constructed after 1954, and the table indicates a probable life of bare steel pipe of between 0 and 9 years.

For all practical purposes, the relationship between the predicted life of a pipe and the resistivity of the soil is reasonably close.

C. Cathodic Protection

The use of cathodic protection, for protecting underground metals, is a common engineering practice. Such a method is quite practical, but cathodic protection requires that close attention be directed to the possibility of corroding adjacent piping systems not included in the piping network under consideration. It is therefore necessary that all underground metallic structures at the institution be

electrically interconnected. However, it is also economical that the building be electrically disconnected from the piping to reduce the necessary quantity of current to protect the piping. In other words, if the reinforcing steel in the buildings is electrically connected, current would be wasted on the non-corroding reinforcing steel.

There is the distinct possibility that a few leaks will appear in the piping soon after the application of cathodic protection. The reason for such leaks is that the pipe may already be so corroded that the corrosion products are acting as a temporary "plug". Movements of the soil or variations in moisture content can loosen the "plug", and the resultant leak will be noticed.

If a leak appears in the piping system near a pipe joint, or other pipe, it is good field practice to electrically bond the pipe sections together as a standard repair procedure. Also, at the conclusion of the installation of the anodes and before the application of cathodic protection, the piping system should be checked for electrical continuity. Any electrical discontinuity of the underground system should be electrically interconnected to prevent the possibility of damage by stray current.

The public utility companies which have service lines in the adjacent area should be notified of the State's intentions so that cooperative tests can be performed to determine if our cathodic system would adversely affect their underground lines.

Since it is contemplated that the hospital install their own cathodic protection system, a representative of the Materials and Research Department will be available to supervise the installation if it is so desired.

It is suggested that, if the cathodic protection system is installed as an emergency nature, a representative of the Division of Architecture be present to supervise the electrical installation and ascertain the conformance to the electrical and building codes.

It is also suggested that the maintenance forces follow a routine program of electrically isolating all utility lines from the buildings. The exception to this would be the sanitary, steam, and electrical power lines.

The purpose of the electrical isolation of the lines would be to greatly reduce the power requirements for cathodic protection. It is anticipated that if electrical isolation is not accomplished, the reinforcing steel in the buildings will at least double the amount of current necessary for protection of the piping.

Since the water piping will be electrically disconnected from the buildings, it appears that ground rods may have to be driven to satisfy the electrical safety requirements for the transformers and equipment in the buildings.

The first phase of the cathodic protection system is implied as an emergency measure. Therefore, the rectifiers which are recommended for use are not of the normal heavy duty type used in cathodic protection applications. However, they are sufficient for this type of emergency work and their purchase will expedite the application of cathodic protection. The emergency rectifiers will also serve the purpose of determining the actual size of the permanent heavy duty type of rectifiers.

At the conclusion of this emergency work, the small rectifiers can be stored and reused either as battery chargers or else they can be once again utilized as a temporary rectifier for other cathodic protection systems at this or other hospitals.

VIII. APPENDIX

A. Tentative Specifications

Rectifiers:

ATR type 620-C Elit, Code Helit "A" Battery Eliminator

Impressed Current Anodes:

"Durion" 1 1/2 x 60" Type D-LO high silicon cast iron anodes, or equal high silicon cast iron anodes.

Anodes shall have a five (5) foot water sealed length of AWG #8 standard copper cable. The coating on the wire shall be Rome CPS OR-1, 600 volt, or Anaconda type CP cathodic protection cable, or equal.

Anode Backfill Materials:

"National" BF-3 backfill consisting of graphite particles and an alkalizer or equal.

Placement of Anodes:

Impressed current anodes shall be placed at the designated locations in the following manner:

1. Auger or otherwise construct anode holes 10 inches in diameter at a depth of 9 feet below the grade of the original ground.

2. Backfill this hole with National BF-3, or equal, backfill material, at a compacted depth of one foot (8 feet below grade).

3. Place and center anode in hole.

4. Continue to place and compact special backfill material in layers not exceeding one foot until the anode has a minimum of one foot of backfill cover.

5. Use a sand or otherwise non-clay porous material to completely backfill the anode installation. Top soil may be used within 6 inches of original ground level for the purpose of growing lawn, etc.

Wiring:

1. Stranded copper anode lead wire shall be 600 volt, AWG size 1/0 Rome cathodic protection cable, CPS OR-1 600 volt, or Anaconda type CP cathodic protection cable or equal.

2. All splices of the anode lead wires to the main feeder lines shall be made by split bolt connector, brazing, or the Cadweld process, or equal.

3. All underground wire splices shall be adequately protected from current leakage through the soil by using a Scotch-cast Splicing Kit containing No. 4 resin or equal.

4. The main feeder wire from the rectifier to the anode beds shall be embedded at least one foot below the grade of the original ground or at a depth which will insure protection of the wire from accidental severance by cultivation, excavation or tampering.

5. The main feeder wire from the rectifier to the anode beds shall be encased in metallic conduit from the rectifier to the depth of burial of the wire. The length of the conduit shall be sufficient to protect the feeder wire from tampering or accidental severance. At the point in the ground where the conduit terminates, a concrete anchor block of at least 12" cube shall be cast to prevent destruction of the conduit by vandalism.

SUGGESTED CATHODIC PROTECTION MATERIAL SUPPLIERS

Harco Corporation
P. O. Box 7026
16901 Broadway Avenue
Cleveland 28, Ohio

Electrical Facilities, Inc.
4224 Holden Street
Oakland, California

Sabins-Dohrmann Company
522 Catalina Boulevard
San Diego 6, California

Frost Engineers Service Co.
P. O. Box 767
Huntington Park, California

Brance Krachy Company
4411 Navigation Boulevard
Houston, Texas

Cathodic Protection Service
310 Thompson Building
Tulsa, Oklahoma

Pipe Line Anode Corporation
Box 996
Tulsa, Oklahoma

Pipeline Coating &
Engineering Company
1566 East Slauson Avenue
Los Angeles 11, California

Vanode Corporation
880 East Colorado Street
Pasadena 1, California

B. Cathodic Protection Cost Estimate

16 each	ATR type 620-C Elit, Code Helit "A" Battery Eliminators	$ 960.00
50 each	1 1/2" x 60" type CLO Durion Anodes . . .	510.00
11,000 LF	1/0 gage, TW 600 volt cable	3,982.00
12,000 lbs.	Type BF-3 lime treated coke breeze . . .	648.00
2 cartons	Burndy Servits, type KS-25 or Reliable split bolt connector No. 1/0 F	114.00
70 each	90-B1 Scotchcast splicing kits	325.00
100 each	Weaver Solderless ground fitting, type "J"	60.00
15 each	Burndy scrulug, type KPA No. KPA 25 . . .	10.00
50 each	Burndy scrulug, type KPA No. KPA 4C . . .	15.00
	Electrical Conduit	200.00
	Excavate 50 anode holes	750.00
	Excavate and Backfill 10,000 LF, trench	2,500.00
	Materials Sub-Total	$10,074.00
	Hospital Labor	2,000.00
	Engineering	1,500.00
	Sub-Total	$13,574.00
	Plus 20% Contingencies	2,714.80
	Total	$16,288.80
	Say	$16,000.00

C. Economic Analysis of Cathodic Protection (Emergency Work)

Estimated yearly cost of sprinkler system without cathodic protection:

Pipe replacement	$ 1,000.00
Repairing leaks	1,800.00
Yearly loss of original piping (10 year basis)	20,000.00
Total	$22,800.00

Estimated yearly cost of cathodic protection:

Installation cost (20 year basis)	$ 800.00
Electrical power	500.00
Maintenance	300.00
Total	$ 1,600.00

Estimated yearly savings from application of cathodic protection $21,200.00

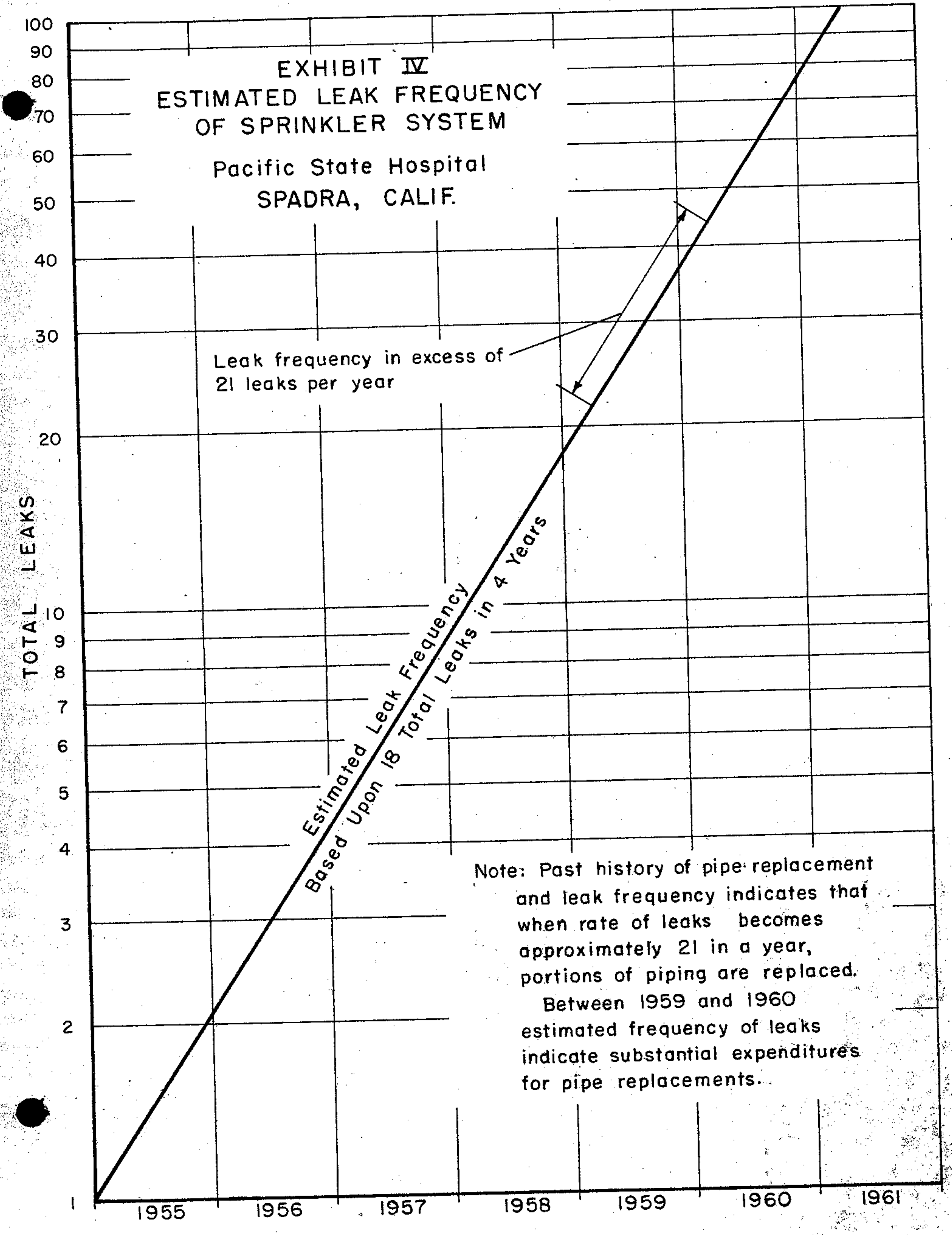


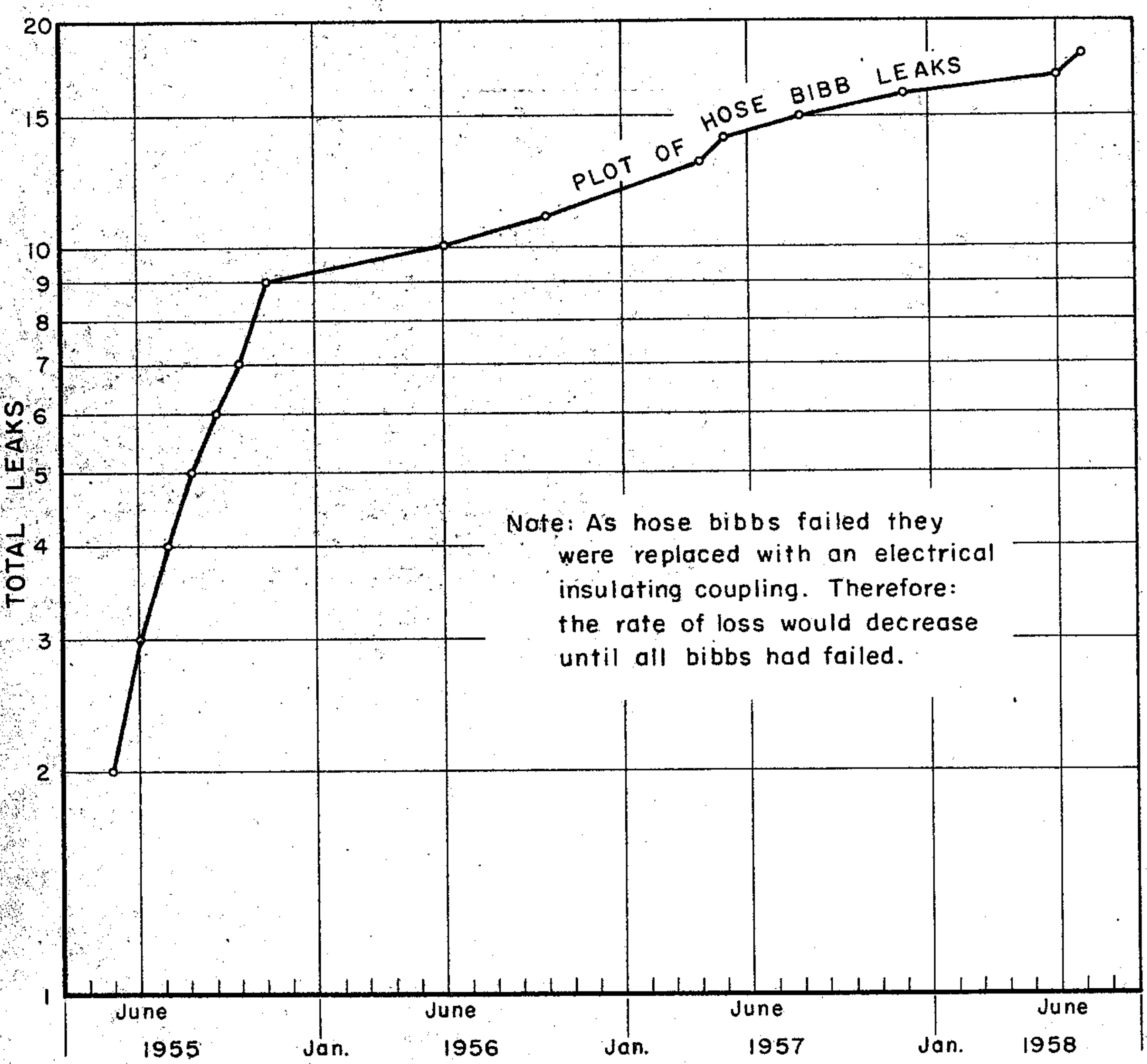
EXHIBIT IV
ESTIMATED LEAK FREQUENCY
OF SPRINKLER SYSTEM
Pacific State Hospital
SPADRA, CALIF.
Leak frequency in excess of
21 leaks per year
Estimated Leak Frequency
Based Upon 18 Total Leaks in 4 Years
Note: Past history of pipe replacement and leak frequency indicates that when rate of leaks becomes approximately 21 in a year, portions of piping are replaced.
Between 1959 and 1960 estimated frequency of leaks indicate substantial expenditures for pipe replacements.
TOTAL LEAKS
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
1955
1956
1957
1958
1959
1960
1961

EXHIBIT V

PLOT OF HOSE BIBB LEAKS VERSUS TIME

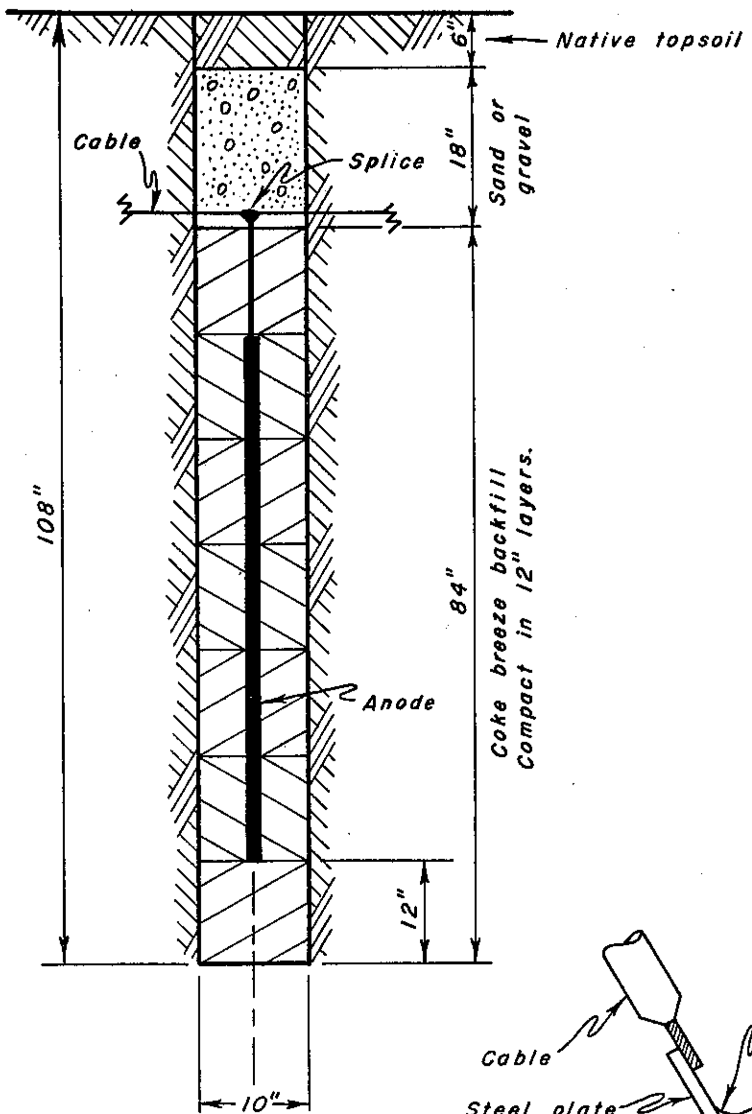
Pacific State Hospital

SPADRA, CALIF.

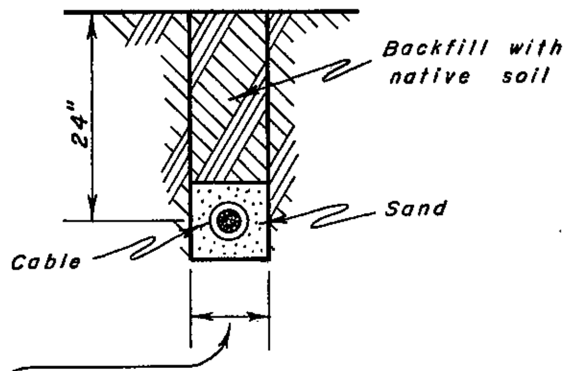


CATHODIC PROTECTION DETAILS

ANODE DETAIL

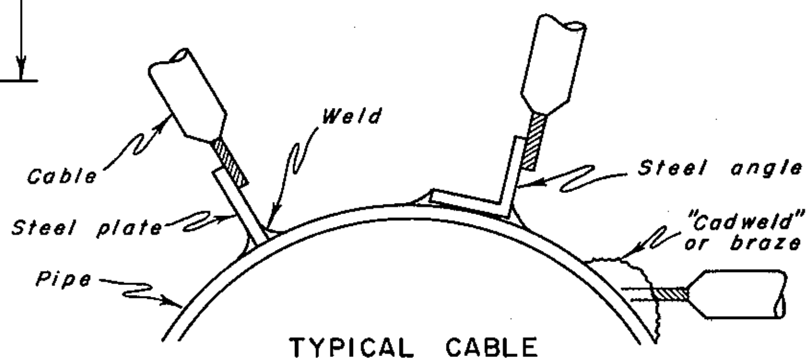


CABLE DETAIL



Cable trench width equals 3" plus O.D. of cable.

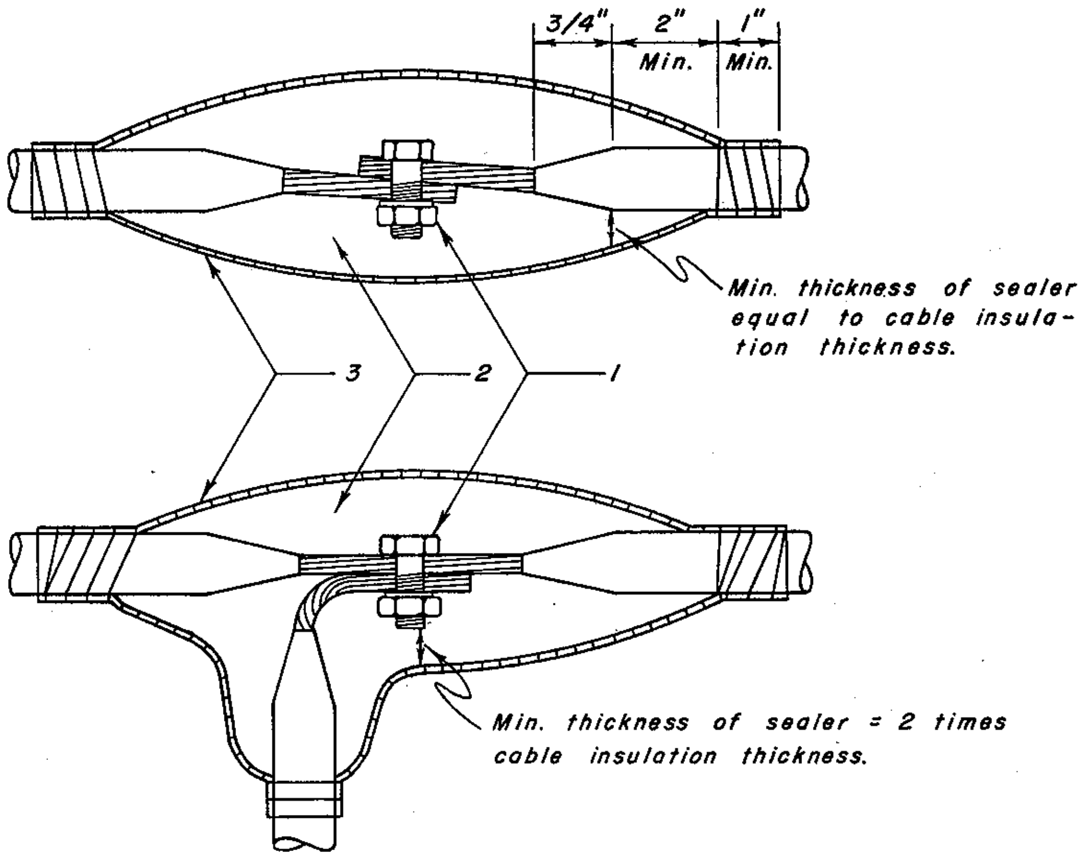
Cable shall have a min. of 1 1/2" sand blanket all around in expansive clay soils. In sandy soils, omit sand blanket and trench width to be minimum of 1" plus O.D. of cable.



TYPICAL CABLE CONNECTIONS TO PIPE

Minimum dimensions of steel connector to be 3/8" thick and 2" in other directions. Cable to have a min. of 1" length brazed or otherwise connected to steel connector or pipe. The steel connector is to be welded all around. Pro-Seal EP-711, or equal, shall be spread a min. of 1/2" thick 3" beyond all exposed metals used for connecting the cable to the pipe. A sand blanket shall be placed 6" in all directions from the cable connection prior to backfilling with native soil.

CATHODIC PROTECTION
CABLE SPLICING DETAIL



1. Split bolt connector or equal.
2. Sealer - Use Pro-Seal EP 711 or equal. (Coast Pro-Seal & Mfg. Co., Los Angeles.)
3. Minimum of three layers half lapped of "Scotch" No. 33 Electrical tape or equal.

OR

1. Welded connection by the "Cadweld Process" or equal.

2.& 3. Scotchcast Splicing Kit utilizing an epoxy type resin or equal.

Note:

Cable at the splice shall be free of dirt, grease, or other foreign matter prior to the application of sealing materials.